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Department of Physics and Astronomy
THE UNIVERSITY OF IOWA
Iowa City, Iowa 52242

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IO SHEATH-ACCELERATED ELECTRONS AND IONS*

by

Stanley D. Shawhan

Department of Physics and Astronomy
The University of Iowa
Iowa City, Iowa 52242

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ABSTRACT

Use has been made of the Pioneer 10 and 11 measurements of the Jovian magnetic field, the Io ionospheric electron density profile, the estimate of the Io atmospheric density, and preliminary measurements of the Jovian ionosphere to revise the Io sheath model. This model suggests that plasma sheaths form between the ionospheric plasma moving with Io and the ambient plasma corotating with Jupiter. Potentials across these sheaths could be as high as 580 kV which is the motional emf across Io's ionosphere. Electrons and ions can be accelerated across these sheaths. The sheaths may exist at the top of the Io ionosphere with characteristic thicknesses of 1/4 kilometers. This model is consistent with the Pioneer observations of > 0.15 MeV electrons at the inner edge of Io's L-shell and the enhanced number density of low-energy protons at the outer edge. Ion sputtering of the Io surface may explain the presence of atomic hydrogen and sodium in the vicinity of Io. Also these accelerated particles may be important to the formation of the Io ionosphere. Directed fluxes of 100 keV electrons in the Io flux tube could be as high as 6×10^9 electrons cm^{-2} sec^{-1}. This flux may lead to the decametric radio emissions, Jovian atmospheric heating and optical and x-ray emissions.

In order to explain the significant modulation of the Jovian decametric radio emissions by the satellite Io (Bigg, 1964) a number of electrodynamical interaction theories have been proposed and are reviewed by Bozyan and Douglas (1976) and by Smith (1976). In general the mechanisms convert rotational energy of Jupiter with respect to the satellite into electromagnetic energy emitted from a small source region near the Jovian ionosphere. Io, for instance, may be involved in the conversion by accelerating a beam of particles, by creating a propagating magnetohydrodynamic disturbance or by sweeping up trapped energetic particles. Results of the various _in situ_ measurements of Pioneer 10 and 11 (_Science_, 1974, 1975) along with recent ground-based observations of intense Sodium-D optical emissions (Brown and Chaffee, 1974) and of Europa-controlled decametric emissions (reviewed by Carr and Desch, 1976) allow definitive tests and refinements of these mechanisms to be made.

At the University of Iowa, a model has been developed in which the rotation of the Jovian magnetic field past Io sets up a potential difference of ~ 580 kV. This homopolar mechanism was first suggested by Piddington and Drake (1968). Plasma sheaths are assumed to exist at the top of the Io ionosphere through which electrons and ions can be accelerated to several hundred kilovolt energies. A beam of energetic electrons may transport the energy to the electromagnetic wave emission region.

This model was first suggested by Gurnett (1972) and has been developed by Shawhan et al. (1973a), Shawhan et al. (1973b), and Hubbard et al. (1974). The model was revised and made more quantitative based on Pioneer 10 preliminary results as discussed by Shawhan et al. (1975).

In this paper recent results available from more rigorously analyzed Pioneer 10 data and the preliminary results of Pioneer 11 are used to further revise this Io sheath model. The revised model is then used to suggest an explanation for a number of Earth-based and Pioneer 10 and 11 observations and to suggest other phenomena which might be detectable with future experiments.

I. SHEATH ACCELERATION MODEL

A complete description of the sheath acceleration model which includes parameters derived from the Pioneer 10 preliminary results is given by Shawhan et al. (1975). The basic assumptions and features include the following:

1. The rotation of the Jovian magnetic field past Io produces a motional potential across Io and its ionosphere which could be as large as 580 kV. The potential is $\phi = vBD'_{Io}$ where v is the velocity of the magnetic field with respect to Io, 56 km sec^{-1} and B is the Jovian magnetic field at Io, 2×10^{-6} webers m^{-2}, for a 4 gauss $R_J{}^3$ dipole moment. D'_{Io} is the effective diameter of Io which is taken to include the 750 km extent of the ionosphere (Kliore et al., 1974a, b).

2. This source of emf can drive a current through the Io ionosphere in the equatorial region, down the Io flux tube into the Jovian ionosphere and across the Jovian ionosphere to return along an Io field line. If the Jovian ionospheric height integrated (Pederson) conductivity is high enough, the Io flux tube will be frozen into the Jovian ionosphere. If the Io ionosphere conductivity is sufficiently high, the Io flux tube can be continually decoupled from the Io ionosphere by a self-consistent current system. The motional potential is not dropped across the ionospheres and is assumed to be dropped at plasma sheaths at the top of the Io ionosphere.

   Gurnett (1972) has derived an expression for the critical Jovian ionosphere conductivity ($\Sigma \sim 10$ mho),. The Pioneer 10 ionosphere and atmosphere results (Kliore et al., 1974) seem to yield sufficient conductivity. Shawhan et al. (1975) used the Pioneer 10 Io atmosphere and ionosphere results (Kliore et al., 1974a, b) to calculate a conductivity of 260 mhos (using the method of Webster et al., 1972). If the neon ionosphere/atrosphere model of Whitten et al. (1975) is applicable, the neutral density of 4×10^9 cm^{-3} would make the Io conductivity marginal.

3. Plasma sheaths form to make the transition from the plasma moving with Io to that corotating with Jupiter. At the top of the ionosphere on the face of Io toward Jupiter,

the plasma potential is negative with respect to the Jovian plasma potential. The opposite face has a positive plasma potential. Therefore we call these transition regions negative and positive sheaths, respectively.

4. The negative sheath accelerates Io ionospheric electrons down the Io magnetic flux tube toward the Jovian ionosphere. Thermal plasma electrons are accelerated through the positive sheath into the Io ionosphere. Because of the dynamic resistance of these sheaths, the motional potential is dropped across these two regions. Accelerated particles can then attain energies of several hundred keV. These two electron fluxes constitute the current system which is closed at the ends of the Io flux tube within the Jovian and the Io ionosphere. The relative surface area on Io covered by the negative and the positive sheaths is determined by the requirement of continuity in the total current; the electron flux times the sheath area must be equal on the two faces of Io. The relative areas then determine the faction of the motional potential available for inward and outward acceleration of particles (Hubbard <u>et al.</u>, 1974).

5. The discontinuity in scale height of the dayside Io ionosphere at 750 km (Kliore <u>et al.</u>, 1974a) is consistent with a sheath at this altitude. Taking the density of 2.5×10^3 electrons cm^{-3} and a temperature for sodium ions of 400°K at the lower side of the sheath with 1/4 of

the flux directed upward, the maximum topside electron current density would be $1 \times$ ·)$^{-5}$ amps m^{-2} emitted from Io at this point. These densit.es and temperatures are also consistent with the Whitten et al. (1975) neon model. This current density corresponds to an electron flux of 6 $\times 10^9$ electrons cm^{-2} sec.

6. Measurements of the thermal plasma density and temperature have now beer obtained from the Plasma Analyzer of Pioneer 10 by Frank et al. (1975). In the vicinity of Io, a maximum ion density of $\sim 100\ cm^{-3}$ with a temperature of 10^6°K may exist. If the electrons have the same density and temperature, a flux of $> 10^{10}$ electrons $cm^{-2}\ sec^{-1}$ may be accelerated into the outward face of Io.

7. Since the inward accelerated electron flux is larger than the outward flux, the outward accelerated electrons would attain a maximum energy which is the larger fraction of the available 580 keV (Hubbard, et al., 1974).

8. Since the sheaths separate two plasma regions with a strong current flowing between them, these sheaths are probably "double layers" as described by Block (1972). From the work of Knorr and Goertz (1974) and of Goertz and Joyce (1974) a typical thickness for the double layer can be calculated. For a number density of $2.5 \times 10^3\ cm^{-3}$, a temperature of 400°K and a potential of 300 kV, the sheath thickness must be on the order of 1/4 km. This sheath size is comparable to a 300 keV electron gyroradius (~ 1 km) but smaller than a 300 keV ion gyroradius (~ 50 km) at Io.

II. PARTICLE ACCELERATION NEAR IO

A qualitative picture of particle acceleration in the vicinity of Io is included in Figure 1. The major features of this particle acceleration are as follows:

A. Face Toward Jupiter (Negative Sheath)

1. Electrons

In the mid and high latitude regions of the Io face toward Jupiter a significant electric field component should exist in the magnetic field direction. Ionospheric electrons from this region can be accelerated to energies up to several-hundred keV. Because of the small random thermal energies, these electrons may have pitch angles well within the Jovian atmospheric loss cone ($\alpha \leq 3°$) and are therefore beamed down the Io flux tube. This beam of $\sim 10^9$ electrons cm^{-2} sec^{-1} from $\sim 1/2$ of Io's area could constitute a current of 10^7 amps which carries up to 10^{13} watts of power.

In the equatorial latitude range the electric field has a significant component directed transverse to the magnetic field lines and if the sheath region is thin enough, and/or the local currents distort the magnetic field in a scale size comparable to the gyroradius, some electrons could gain a substantial amount of perpendicular energy which would trap them on field lines just inside Io's orbit.

2. Ions

This same negative sheath can accelerate ions to several hundred keV energies into the Io atmosphere toward the Io surface. An estimate of the proton flux can be made by assuming $T_i = 10^6$°K, $n_i = 100\ cm^{-3}$ from Frank et al. (1975). The flux is then ~ 2 x 10^8 protons $cm^{-2}\ sec^{-1}$ ~ 100 keV. These fluxes exceed energetic proton fluxes measured by Pioneer 10 and 11 (Science, 1974, 1975), and may be significant for ion-sputtering of the Io surface.

B. Face Away From Jupiter (Positive Sheath)

1. Electrons

Thermal plasma electrons from the magnetosphere can be accelerated through the positive sheath region to several hundred keV energies. As indicated in Figure 1 these electrons are directed into the ionosphere and atmosphere of Io. The fluxes may be in the range of 10^9 to 10^{10} electrons $cm^{-2}\ sec^{-1}$ which is sufficient to cause optical emissions, impact ionization and heating. Primary and secondary electrons are conducted into the negative sheath region to complete the electron current circuit.

2. Ions

Ionospheric ions are accelerated through the sheath away from Io. Because of the small sheath size compared

to a gyroradius or to the scale size of the distorted magnetic field most of these ions should gain perpendicular energy and be trapped on field lines just outside Io's orbit. For protons the flux could be as high as 2×10^8 ions cm^{-2} sec^{-1} and for sodium ions of 5×10^7 ions cm^{-2} sec^{-1} for energies not higher than ~ 100 keV.

Important quantities deduced for the Io sheath acceleration model are summarized in Table I.

III. EVIDENCE FOR THE SHEATH ACCELERATION MODEL

Prior to the Pioneer 10 flyby of Jupiter, Shawhan et al. (1973b) had suggested that Io might be the dominant source of energetic electrons in the Jovian magnetosphere up to energies of 3 MeV. This suggestion was made in light of predicted extreme satellite sweep up effects of inward diffusing solar wind plasma (e.g. Hess et al., 1973). It is clear from the in situ particle measurements of Pioneer 10 and 11 (Science, 1974 and 1975) that satellite sweep up effects are not as severe as predicted, that characteristic electron energies extend to several tens of MeV and that acceleration must occur over a wider region than that associated with Io. Simpson et al. (1974) points out that this Io sheath acceleration process is not a major source in the Jovian magnetosphere. However, evidence from Pioneer 10 and 11 suggests that this process may be important for particle acceleration in the vicinity of Io and may provide the necessary source of energy to power the decametric radio emissions.

The most convincing evidence for particle acceleration at Io comes from the Pioneer 10 and 11 results of the UCSD trapped radiation detector (Fillius and McIlwain, 1974, and Fillius et al., 1975). A spike in the soft electron flux ($>$ 150 keV) occurs at the innermost edge of the Io band of L-shells for both the inbound and outbound passes of Pioneer 10. Fillius and McIlwain (1974) conclude that these spikes are too narrow to have undergone much diffusion. Also the angular distributions of the electrons are more concentrated perpendicular to the magnetic field than elsewhere. Both of these passes were far from the instantaneous Io flux tube; enhancements in flux of $\sim 10^7$ electrons cm^{-2} sec^{-1} were observed. The outbound spike is shown in Figure 2 (from Frank et al., 1975) at $\sim$ 0640 ERT. Electron detectors at $E_e > 9$ MeV showed no spike. The flux for a threshold of $E_e > 460$ keV showed less enhancement than did the $E_e >$ 255 and $E_e > 160$ keV fluxes (Fillius and McIlwain, 1974).

Pioneer 11 passed within $\sim$ 6000 km of the Io flux tube (D_2 Model) on the inbound pass. A jump in the electron flux for $E > 460$ keV of 4×10^8 electrons cm^{-2} sec^{-1} was observed (Fillius, et al., 1975). This flux near the Io flux tube can be compared to the flux possibly accelerated from Io. Using the flux value of 6×10^9 electrons cm^{-2} sec^{-1} for the range up to $\sim$ 500 keV in energy and considering that the integral flux above 460 keV is $\sim$ 0.1 of this value ($\Delta E/E \sim$ 50 keV/ 500 keV) one obtains $\sim 6 \times 10^8$ electrons cm^{-2} sec^{-1} expected in the flux tube above 460 keV. This same enhancement appears in the data of Van Allen et al., (1975). The pitch angle distribution of these electrons

have not been determined in detail although they tend to be perpendicular to the field line (D. D. Sentman and R. W. Fillius, private communications). It is not known whether the distribution constitutes a field aligned current.

Io is also expected to accelerate ionospheric ions from its face away from Jupiter into the region around Io. If the electron energies range up to ~ 500 keV then these ion energies must be less than 100 keV. Simpson et al. (1974) report no evidence of protons > 500 keV with the Pioneer 10 LET in the vicinity of Io, as expected.

Carefully subtracting off the flux of the high energy particles penetrating into the Ames Research Center Plasma Analyzer Experiment on Pioneer 10, Frank et al. (1975) have found distinct regions of high temperature ion plasmas. The outbound proton density data in the range of 108 eV to 4.8 keV is shown in Figure 2. Frank et al. (1975) interpret the steep fall off in number density of radial distances of 3 to 7 R_J as a plasmapause which may be associated with Io. Superimposed on the steep gradient is a twofold enhancement in the ion density (~ 10 cm^{-3}) at Io with the peak density occurring toward the range of Io L-shells away from Jupiter. This enhancement is consistent with ions being injected from the Io ionosphere. An even larger enhancement was observed on the inbound pass.

With Figure 2 a spatial comparison of the energetic electron flux and the ion density can be made. The electron flux tends to peak toward Jupiter and the ion density away from Jupiter in the Io L-shell region as expected from the Io sheath acceleration model.

IV. EXPLANATION OF OTHER IO-RELATED PHENOMENA

Io-related phenomena, other than energetic particles, observed at Earth and with Pioneer 10 and 11 seem to be consistent with the Io sheath acceleration model. A summary of these phenomena and the significance of the Io accelerated particles follows. A more detailed discussion is given by Shawhan et al. (1975).

Figure 3 depicts the Io orbit around Jupiter and some possible consequences of the accelerated particles. The existence of ~ 500 keV electrons trapped just inside the Io L-shells and of hot ions just outside has been discussed. Other phenomena include

A. Io-Associated Sodium-D Optical Emissions

Ion sputtering of the Io surface seems to be the most plausible explanation for the release of Sodium into the vicinity of Io (Matson et al., 1974 and McElroy and Yung, 1975). which results in intense Sodium-D emission (e.g. Brown and Chaffee, 1974). Our model accelerates ions into the face of Io toward Jupiter. This is the face for which Trafton et al. (1974) observed the more intense Sodium emissions. A flux of Sodium atoms of 2 x 10^7 atoms cm^{-2} sec^{-1} is necessary to maintain the observed sodium cloud (McElroy and Yung, 1975) which requires an incident energetic proton flux of 10^8 cm^{-2} sec^{-1}, a lower flux of required heavier energetic ions or a cascade process due to acceleration of liberated sodium ions (Matson et al., 1974). According to our calculations the proton flux accelerated by Io would be 10^8 cm^{-2} sec^{-1}. The primary ener-

getic ion fluxes $>$ 0.15 MeV as observed with Pioneer 10 and 11 (Science, 1974, 1975) are insufficient to provide the necessary sodium flux by at least an order of magnitude. However, the ambient lower energy ion flux was not measured.

Collisional excitation of the Sodium (McElroy and Yung, 1975) could be due to the flux of $\sim 10^{10}$ electrons cm^{-2} sec^{-1} that are accelerated into the Ion atmosphere on the face away from Jupiter.

B. Io-Associated Hydrogen Torus

Carlson and Judge (1974) report further analysis of the Pioneer 10 UV Photometer data. They conclude that a hydrogen cloud exists extending in a partial torus of 120° along the orbit of Io and centered at Io. According to McElroy and Yung (1975) this neutral hydrogen flux could result from photolysis of atmospheric NH_3. We propose that ion sputtering of the Io surface by $\sim 10^8$ ions cm^{-2} sec^{-1} could liberate the NH_3 as with Sodium. The hydrogen cloud limited spatial extent sets a lifetime of $\sim 2 \times 10^5$ seconds for the atoms. As pointed out by Carlson and Judge (1974) a charge exchange process with the ion plasma is a sufficient loss process. Frank et al. (1975) have shown that this loss is consistent with the observed Pioneer 10 ion densities. These ions just at the Io orbit may be sheath accelerated out of the Ion ionosphere (see Section III).

C. Io Ionosphere

We suggest that the significant Io ionosphere and inferred atmosphere deduced from occultation of the Pioneer 10 S-band

transmission (Kliore *et al.*, 1973a, b) may be controlled by the sheath acceleration process. On the face toward Jupiter ("day" at the time of the Pioneer 10 occultation) ions are accelerated inward to cause sputtering and inflation of the ionosphere. On the opposite face ("night") ions are lost so that the ionosphere would be significantly deflated consistent with observations. Analysis of the ionosphere by McElroy and Yung (1975) seems to require such processes. However, a neon atmosphere proposed by Whitten *et al.* (1975) does not.

D. Jupiter-Associated X-Rays

Remote measurements have been made to detect Jovian x-rays using the UHURU (Hurley, 1975) and Copernicus (Vesecky, 1975) satellites. Upper limits to the x-ray flux at the Earth in the energy range of 2-6 keV are 5×10^{-4} cm^{-2} sec^{-1} and in the range 0.6 to 1.9 keV are 8×10^{-3} cm^{-2} sec^{-1} respectively. An order of magnitude estimate can be made from the Io sheath model for the x-ray flux from the Jovian atmosphere at the foot of the Io flux tube and from the Io atmosphere. For both cases the corresponding flux at the Earth would be 10^{-5} photons cm^{-2} sec^{-1} keV^{-1} which is more than an order of magnitude below the detection limit of either experiment. To detect these x-rays it seems that a Jupiter orbiter experiment located outside of the hard trapping region is necessary.

E. Jovian Atmospheric Ionization, Heating and Optical Emissions

If the electrons in the Io flux tube fall within the

atmospheric loss cone due to the initial acceleration process or by pitch angle scattering, then ionization, optical emissions and atmospheric heating should result as the energy carried by these electrons is dissipated in the atmosphere. The Pioneer 11 measurements near the flux tube indicate a flux for electrons > 460 keV of $\sim 10^8$ electrons cm^{-2} sec^{-1} (Fillius et al., 1975). The model gives a total flux of 6×10^9 electrons cm^{-2} sec^{-1}.

A model calculation using the predicted flux yields a maximum density of 10^4 electrons cm^{-3} at 200 km (for a radiative recombination coefficient of 6.6×10^{-12} cm^3 sec^{-1}) which is 10% of the photoionized density.

Optical emissions associated with the probable atmospheric constituents (H, H_2, He, CH_4 and NH_3) are expected due to energetic electron excitation. These electrons could be those precipitating due to Io or those precipitating from the radiation belts. For the Io-related electrons a power flux of 10^{13} watts spread over 10^5 km^2 (10^{-5} of the disk area) yields a maximum energy flux of 10^5 ergs cm^{-2} sec^{-1}. Rees (1973) has carried out model calculations that indicate an upper limit Hα (6563 Å) intensity of about 10^3 kR. Intense radiations with 10^4 kR could occur for the Lyman series from H_2, for the Werner series from H_2 and for some singlet line emissions from He especially at 10,830 Å.

Assuming that the other losses are insignificant, the 10^5

ergs cm^{-2} sec^{-1} energy flux could go into atmospheric heating. Consequently, a hot spot or warm strip may exist associated with the foot of the Io field line.

V. SATELLITE MODULATION OF DECAMETRIC RADIO EMISSIONS

Direct energetic particle measurements by Fillius et al. (1975) seem to substantiate the existence of energetic electrons with energies up to ~ 500 keV in, or at least near to, the Io flux tube. This observed flux of 4×10^8 electrons cm^{-2} sec^{-1} taken to be spread over a radius of 6000 km for 500 keV electrons would carry 3×10^9 watts of power as a lower limit. The model beam would carry ~ 10^{13} watts. Jovian decametric bursts have intensities of ~ 10^8 watts (Warwick, 1967 and Carr and Gulkis, 1969).

A perhaps analogous source of radio emissions comes from detailed measurements of the Earth's auroral kilometric radiation (e.g., Gurnett, 1974). This noise is also very intense (~ 10^9 watts), is beamed into a cone and shows close association with the "inverted-V" electron precipitation events in the auroral zone and with bright auroral arcs. The peak emission frequency (~ 300 kHz) scales approximately to the peak Jovian emission frequency (~ 9 MHz) as the magnetic fields in the assumed emission regions. Also the mapping of the Io flux tube into the distorted surface magnetic field by Acuna and Ness (1975) and Smith et al. (1975) indicates that the ionospheric field may reach a field value consistent with the 40 MHz upper frequency cutoff of the decametric emissions assuming that the decametric emission occurs near the electron gyrofrequency.

In the case of the Earth the source of the "inverted-V" electrons may be a double layer in the 1.5 to 3 R_E range (Block, 1972). Shawhan _et_ _al._ (1973a) have suggested that besides the double layers near Io, other double layers may form in the Jovian ionosphere which could lead to the decametric emissions. Mechanisms for Earth kilometric (and possibly Jovian decametric) emissions from energetic electron beams have been suggested by Benson (1975), Melrose (1975) and Palmadesseo et al. (1975). Lower potential sheaths systems should form at Europa which may explain the Europa control near 1 MHz.

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TABLE I

TABLE OF PHYSICAL QUANTITIES

	Parameter	Value
1.	Maximum sheath potential (Maximum particle energies)	400 kV across Io 580 kV across Io ionosphere
2.	Characteristic sheath thickness at ~ 750 km altitude above Io ionosphere	~ 1/4 km
3.	Io ionospheric conductance (height integrated)	260 mhos
4.	Maximum current density in Io flux tube near sheath;	1×10^{-5} amps m^{-2}
	Maximum electron flux in Io flux tube near sheath < 580 keV	6×10^{9} electrons cm^{-2} sec^{-1}
5.	Maximum ion flux available for sputtering < 580 keV	2×10^{8} ions cm^{-2} sec^{-1}
6.	Maximum electron flux precipitating into Io atmosphere for thermal plasma around Io of ~ 100 cm^{-3} at 10^{6}°K	~ 10^{10} electrons cm^{-2} sec^{-1}
7.	Maximum outward flux of energetic Na^{+}-ions	5×10^{7} ions cm^{-2} sec^{-1}
8.	Maximum power carried down Io flux tube	~ 10^{13} watts

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FIGURE CAPTIONS

Figure 1 Particle acceleration in the vicinity of Io.

Figure 2 Fluxes of > 160 keV electrons and number density of 108 eV to 4.8 keV ions for the outbound pass of Pioneer 10 indicating the enhancements at the Io L-shell region (Figure 11 of Frank *et al.*, 1975).

Figure 3 Consequences of Io sheath-accelerated particles.

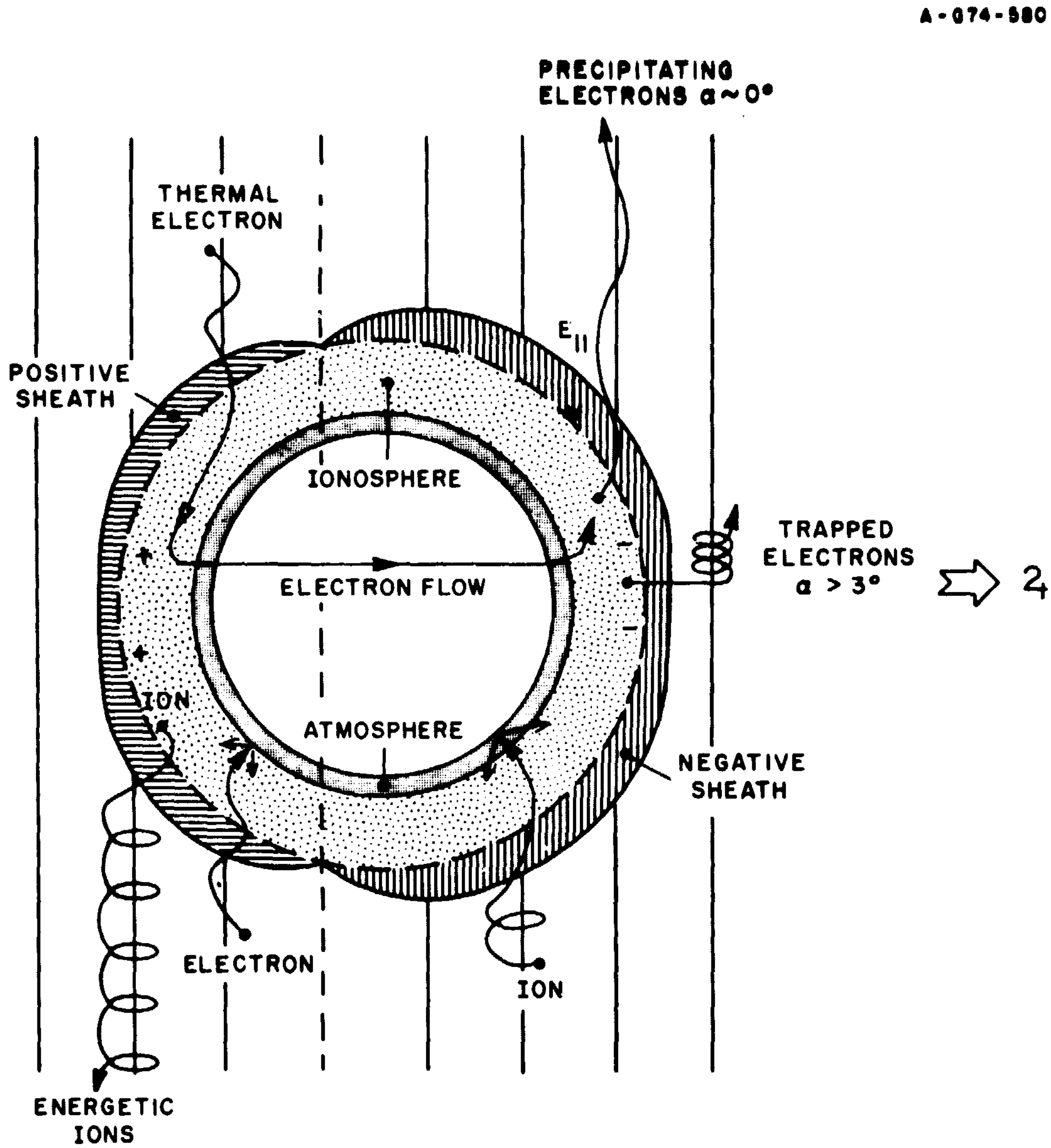
A-074-580
PRECIPITATING
ELECTRONS α~0°
THERMAL
ELECTRON
E∥
POSITIVE
SHEATH
IONOSPHERE
TRAPPED
ELECTRONS
α > 3°
2
ELECTRON FLOW
ION
ATMOSPHERE
NEGATIVE
SHEATH
ELECTRON
ION
ENERGETIC
IONS

Figure 1

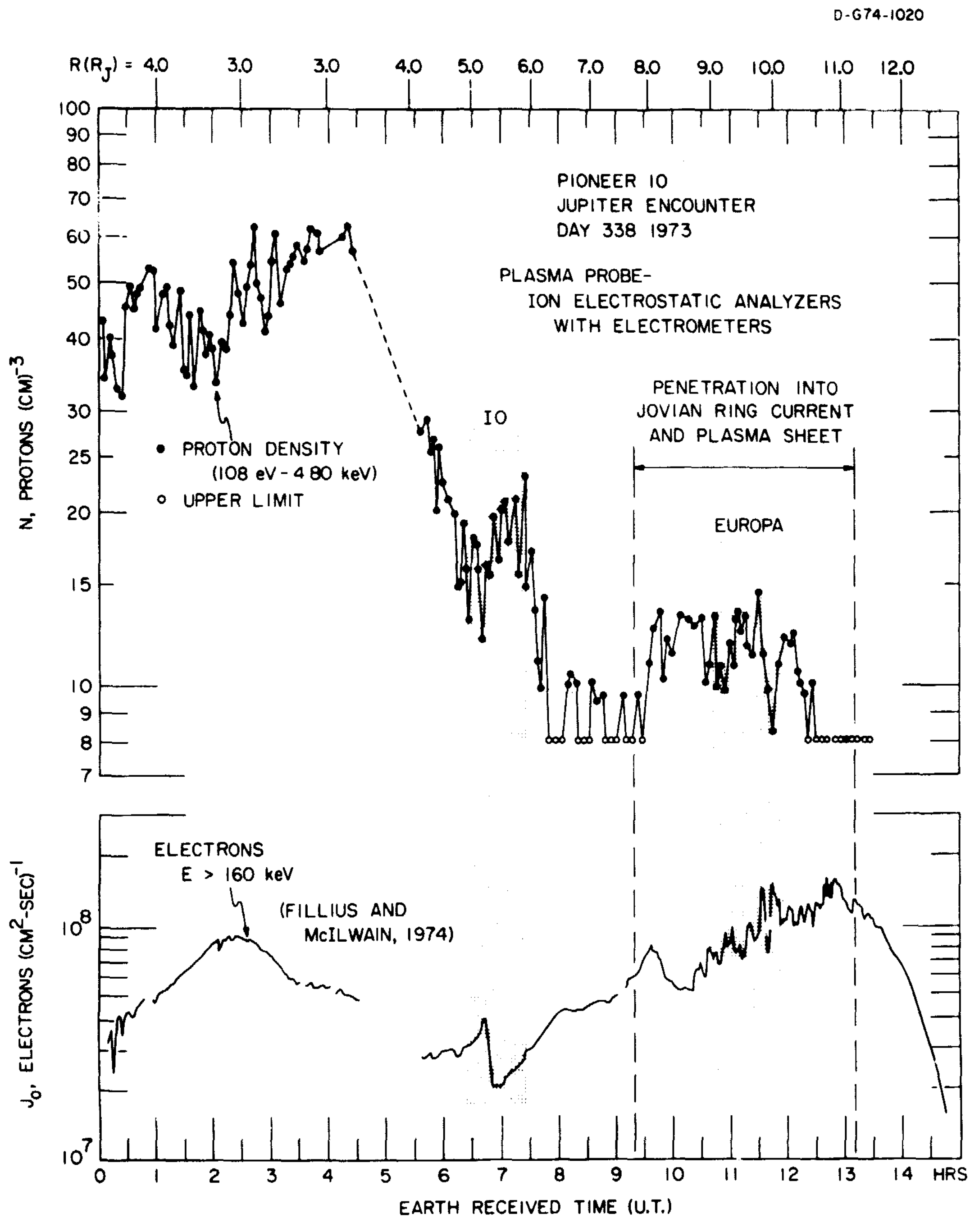
D-G74-1020
R(R_J) = 4.0 3.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0
PIONEER 10
JUPITER ENCOUNTER
DAY 338 1973
PLASMA PROBE-
ION ELECTROSTATIC ANALYZERS
WITH ELECTROMETERS
PENETRATION INTO
JOVIAN RING CURRENT
AND PLASMA SHEET
IO
EUROPA
PROTON DENSITY
(108 eV - 4 80 keV)
UPPER LIMIT
N, PROTONS (CM)^-3
ELECTRONS
E > 160 keV
(FILLIUS AND
McILWAIN, 1974)
J_0, ELECTRONS (CM^2-SEC)^-1
EARTH RECEIVED TIME (U.T.)
HRS

Figure 2

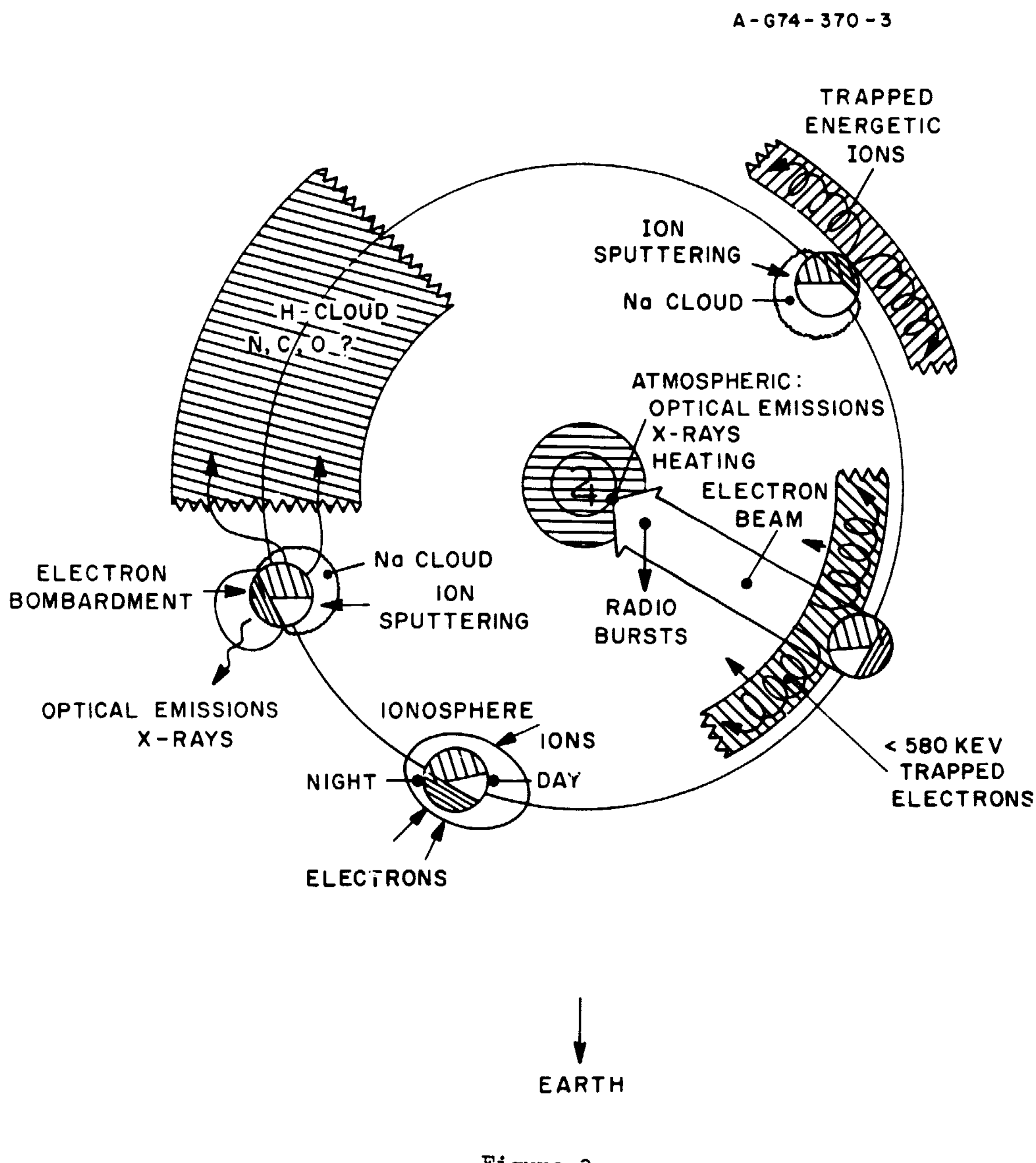
A-G74-370-3
TRAPPED
ENERGETIC
IONS
ION
SPUTTERING
Na CLOUD
H-CLOUD
N, C, O ?
ATMOSPHERIC:
OPTICAL EMISSIONS
X-RAYS
HEATING
ELECTRON
BEAM
ELECTRON
BOMBARDMENT
Na CLOUD
ION
SPUTTERING
RADIO
BURSTS
OPTICAL EMISSIONS
X-RAYS
IONOSPHERE
IONS
NIGHT
DAY
ELECTRONS
< 580 KEV
TRAPPED
ELECTRONS
EARTH

Figure 3